Comparisons among neutron-star mergers and heavy-ion collisions

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Neutron-star mergers:

Phys. Rev. Lett. 122 (2019) 6, 061101, e-Print: 1807.03684
Eur. Phys. J. A 56 (2020) 2, 59, e-Print: 1910.13893

3D phase diagrams:

Phys. Rev. D 102 (2020) 7, 076016, e-Print: 2004.03039
J.Phys.Conf.Ser. 1602 (2020) 1, 012013, e-Print: 2010.00996
e-Print: 2011.11686

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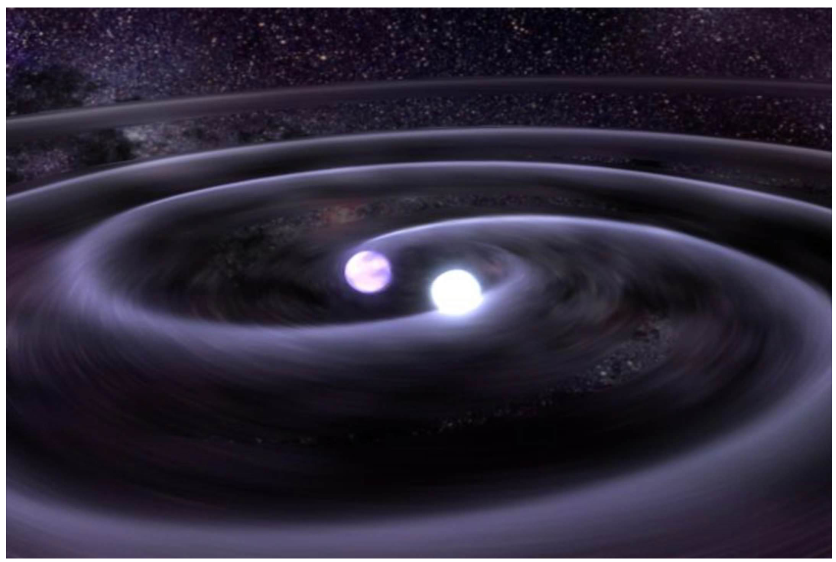
PHAROS
THE MULTI-MESSENGER PHYSICS AND ASTROPHYSICS OF NEUTRON STARS

NSF

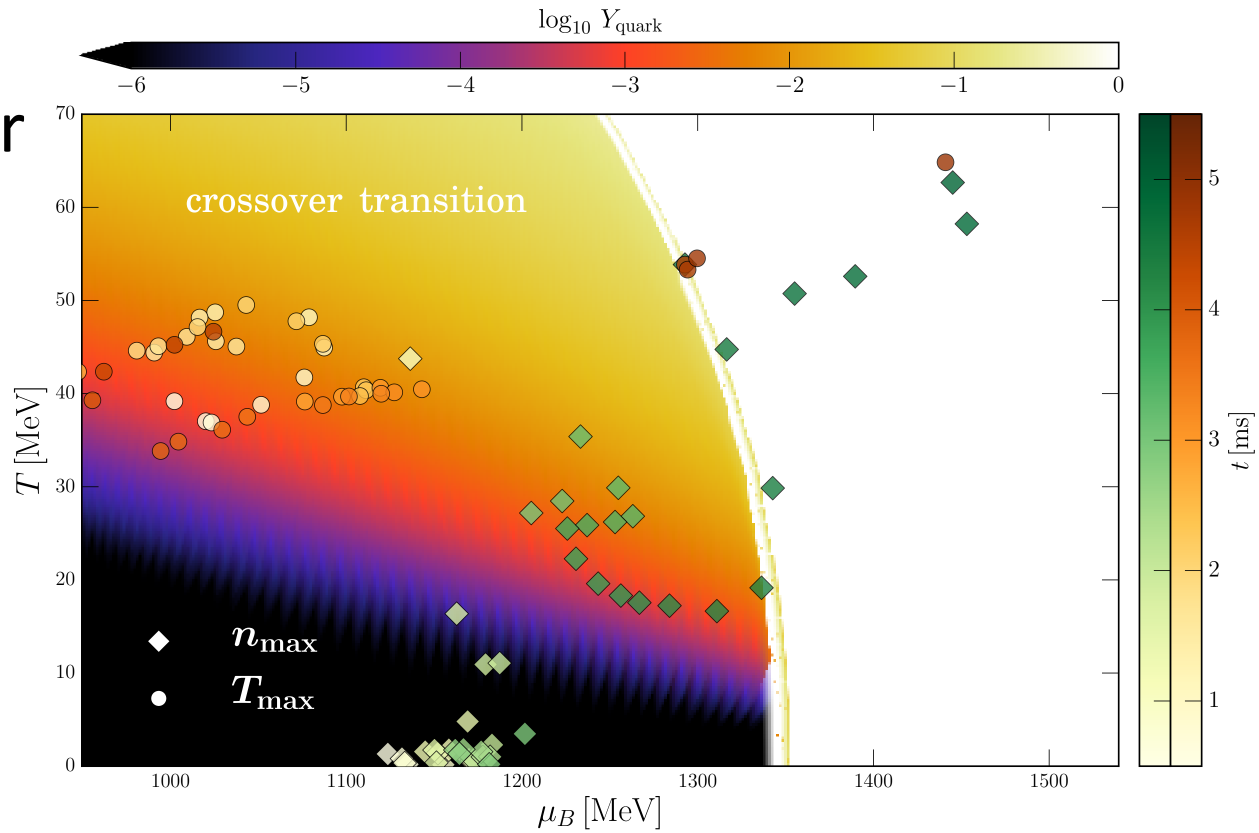
Charge Fraction Y_Q=Q/B overview

- Heavy-ion collisions: 0.4 → 0.5
- Cold catalyzed neutron stars cores: 0 → 0.15
- Supernovae explosions and proto-neutron stars: 0.1 → 0.5 (0.4)
- Neutron-star mergers ?



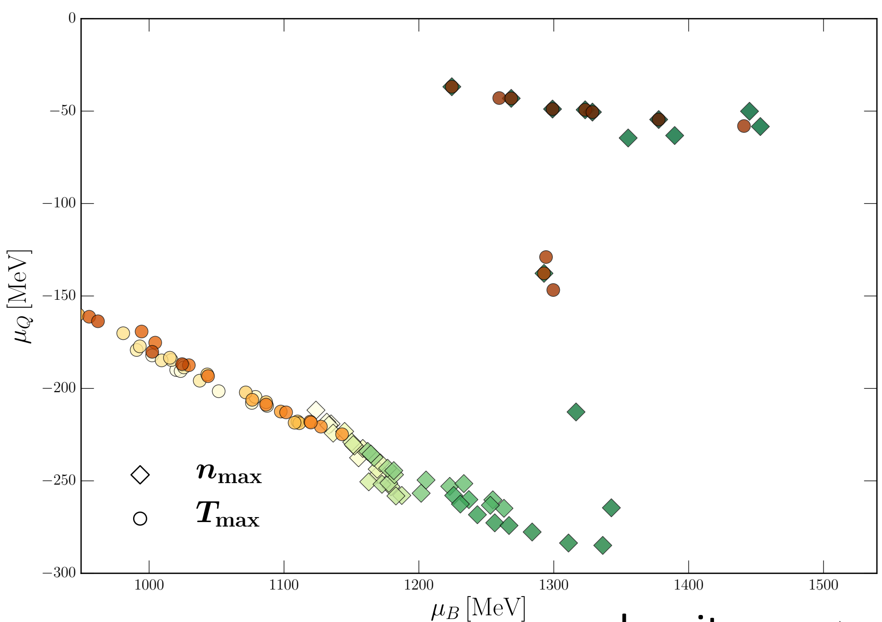
Merger in the QCD Phase Diagram

- Background: 2D (T,n_B) CMF EoS $Y_Q=Q/B=0.05$
- Solve coupled Einstein-hydrodynamics system using (FIL)
- 3D (T,n_B,Y_Q) CMF EoS with 1^{st} order phase transition for binaries with mass 2.9 M_{sun}
- Tracking maximum temperature ● and density ◆

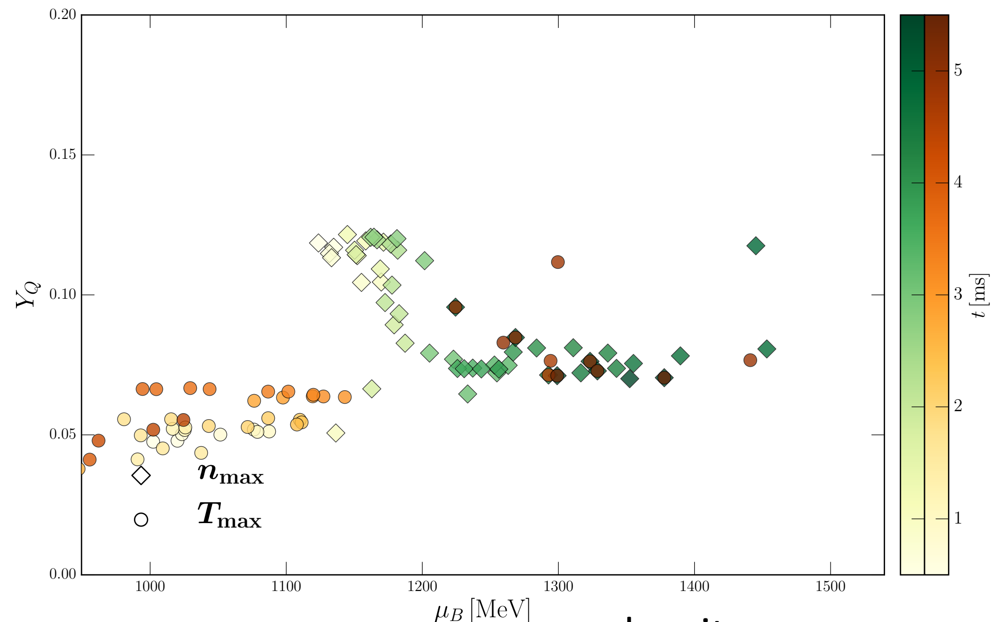


More Phase Diagrams

- Tracking maximum temperature ● and density ◆



density ρ_B ⟶



density ρ_B ⟶

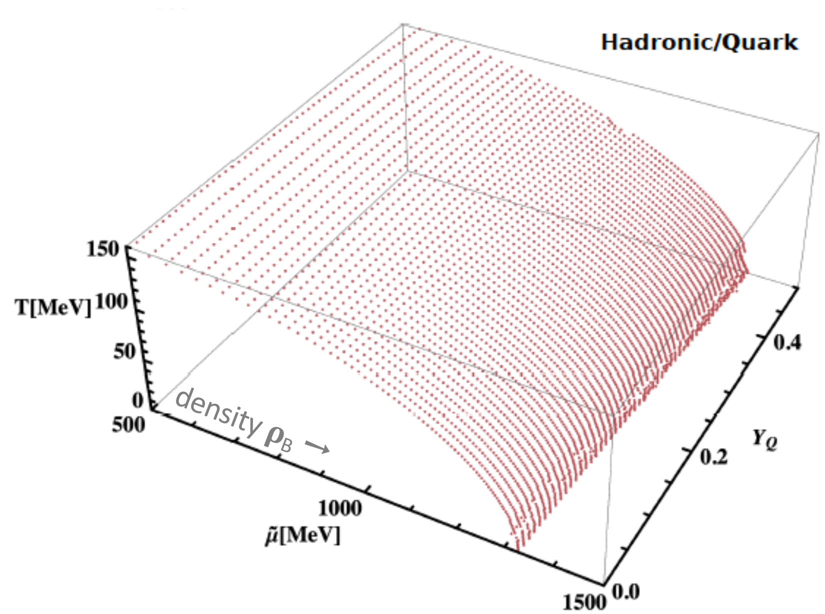
- Increase in abs. value of charged chemical potential until phase transition, when it drops

- Decrease in charge fraction of core when quarks appear (not reaching heavy-ion/supernovae conditions)

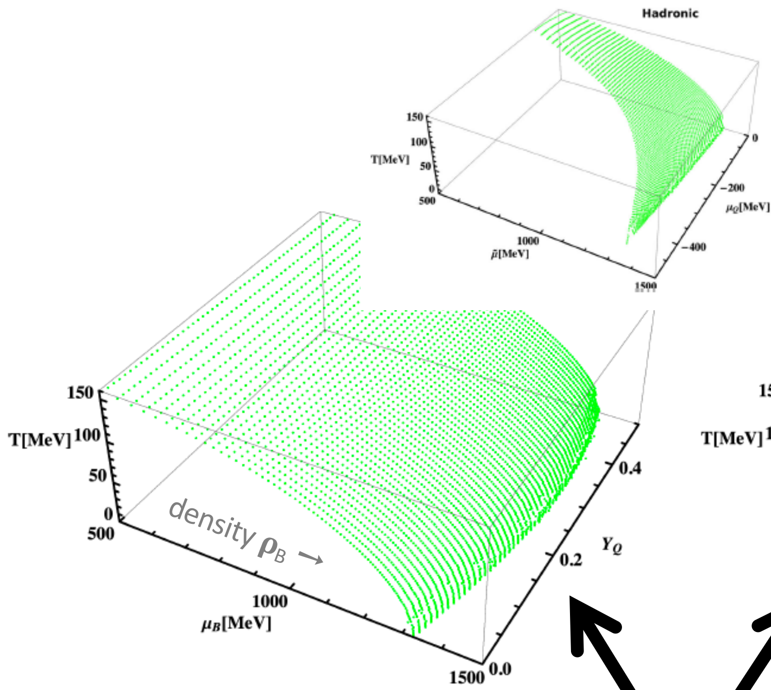
3D QCD Phase Diagrams (Y_S=0)

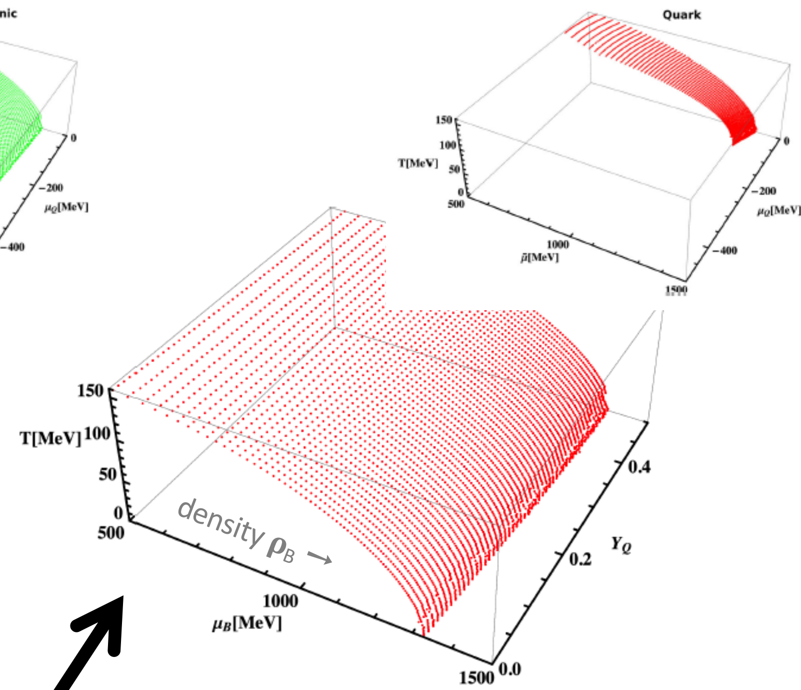
- T, $\widetilde{\mu}$,Y_Q with charge fraction $Y_Q = Q/B$ = 0 → 0.5
  and Gibbs free energy per baryon $\widetilde{\mu} = \mu_B + Y_Q \mu_Q$

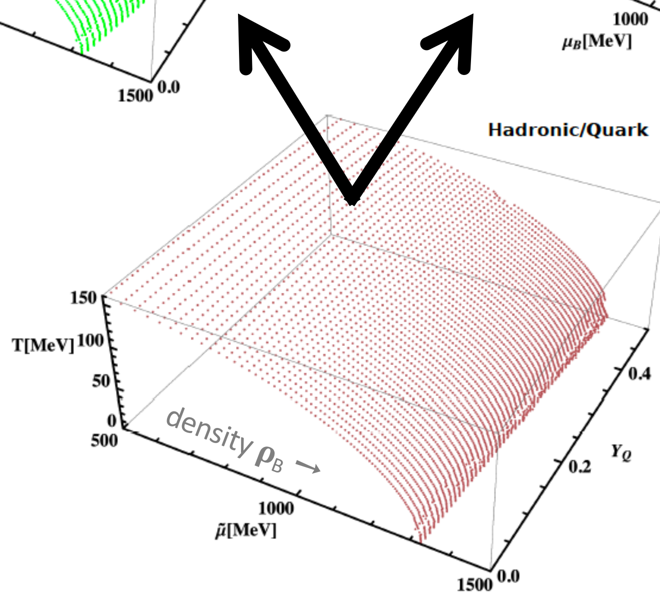
- Larger Y_Q (at fixed T) pushes the phase transition to larger $\widetilde{\mu}$
- Changes due to Y_Q effects on the EoS (particle population) on each side



3D QCD Phase Diagrams (Y_S=0)





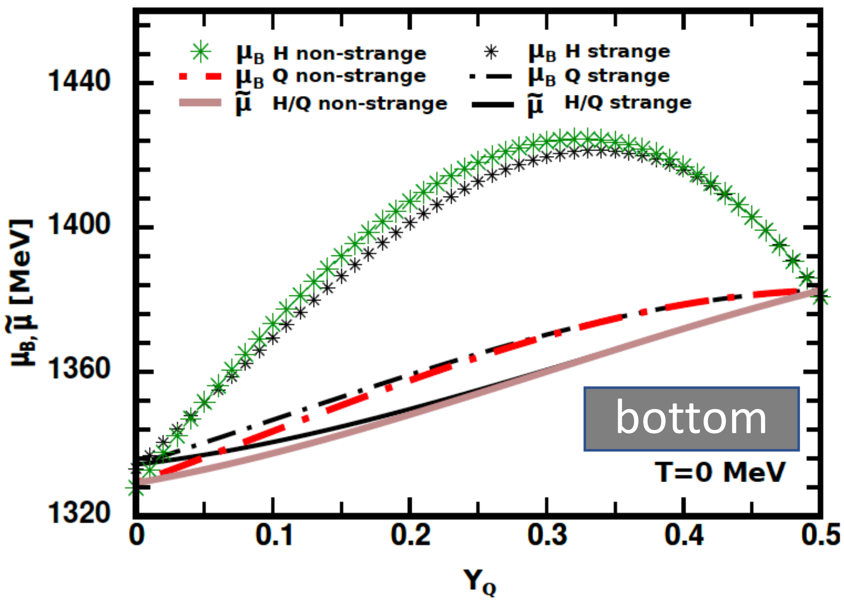


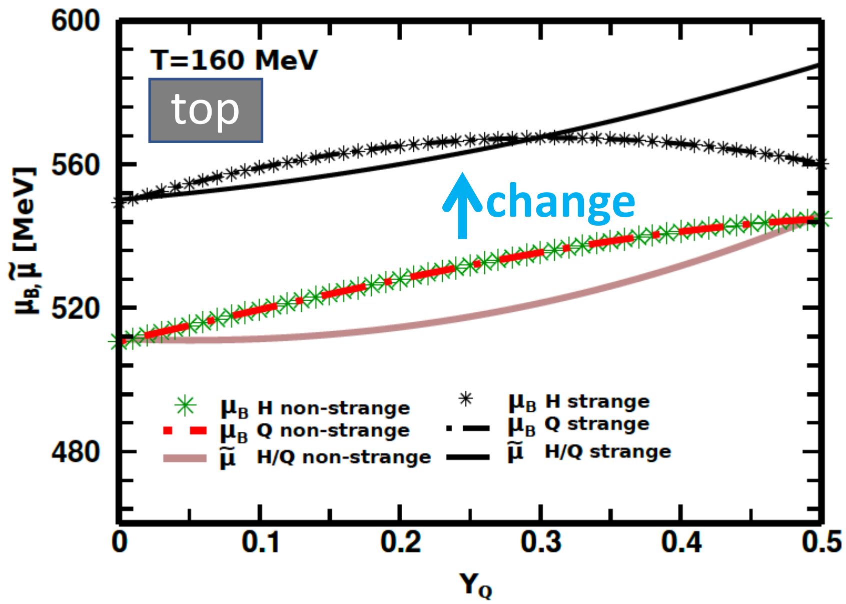
Gibbs free energy per baryon

$\widetilde{\mu} = \mu_B + Y_Q \mu_Q$

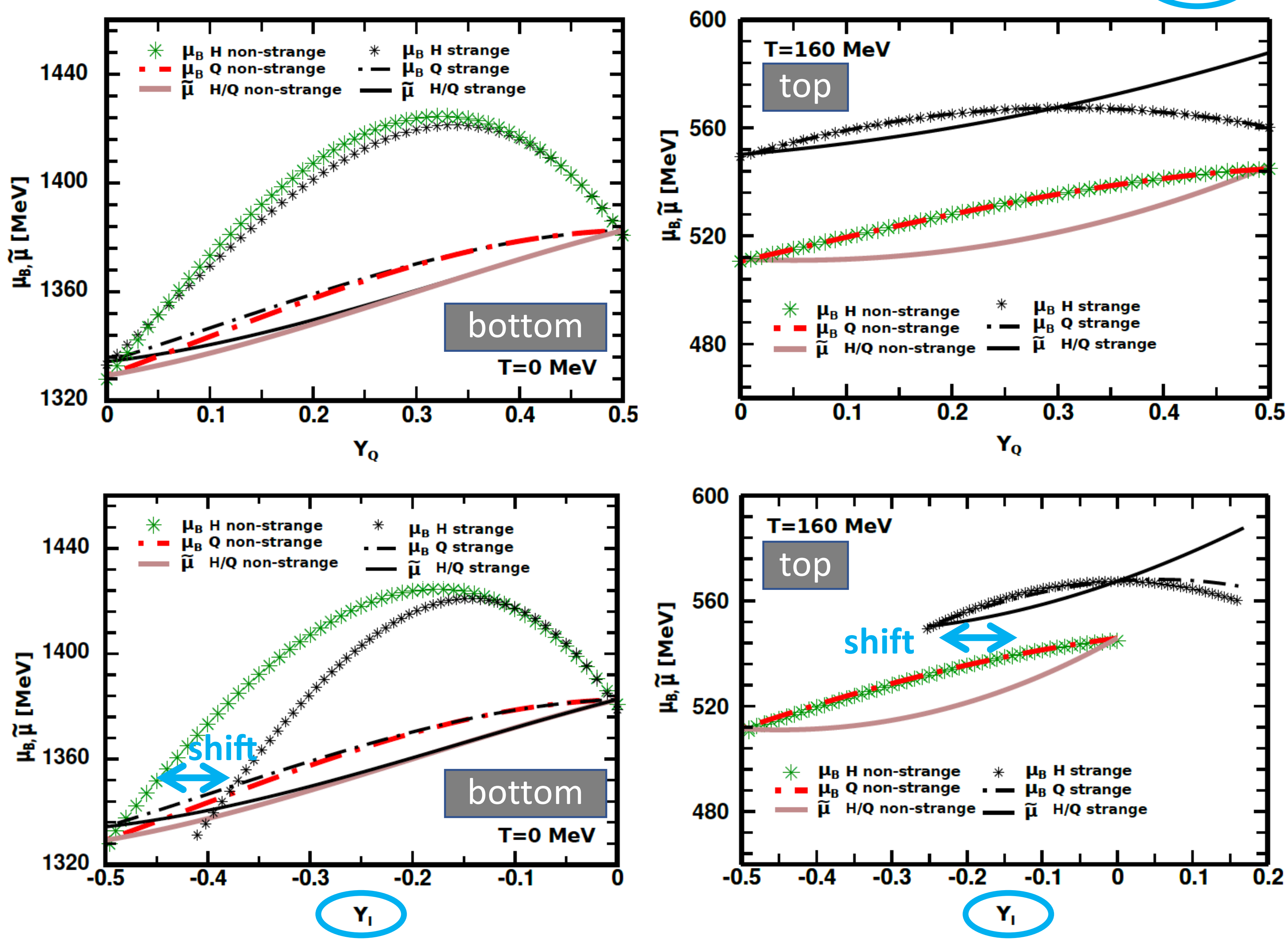
Slices of 3D QCD Phase Diagrams
(Y_S=0, $Y_S \neq 0$ in black)

- For finite net strangeness $Y_S \neq 0$, deconfinement takes place at larger free energy/ baryon chemical potential



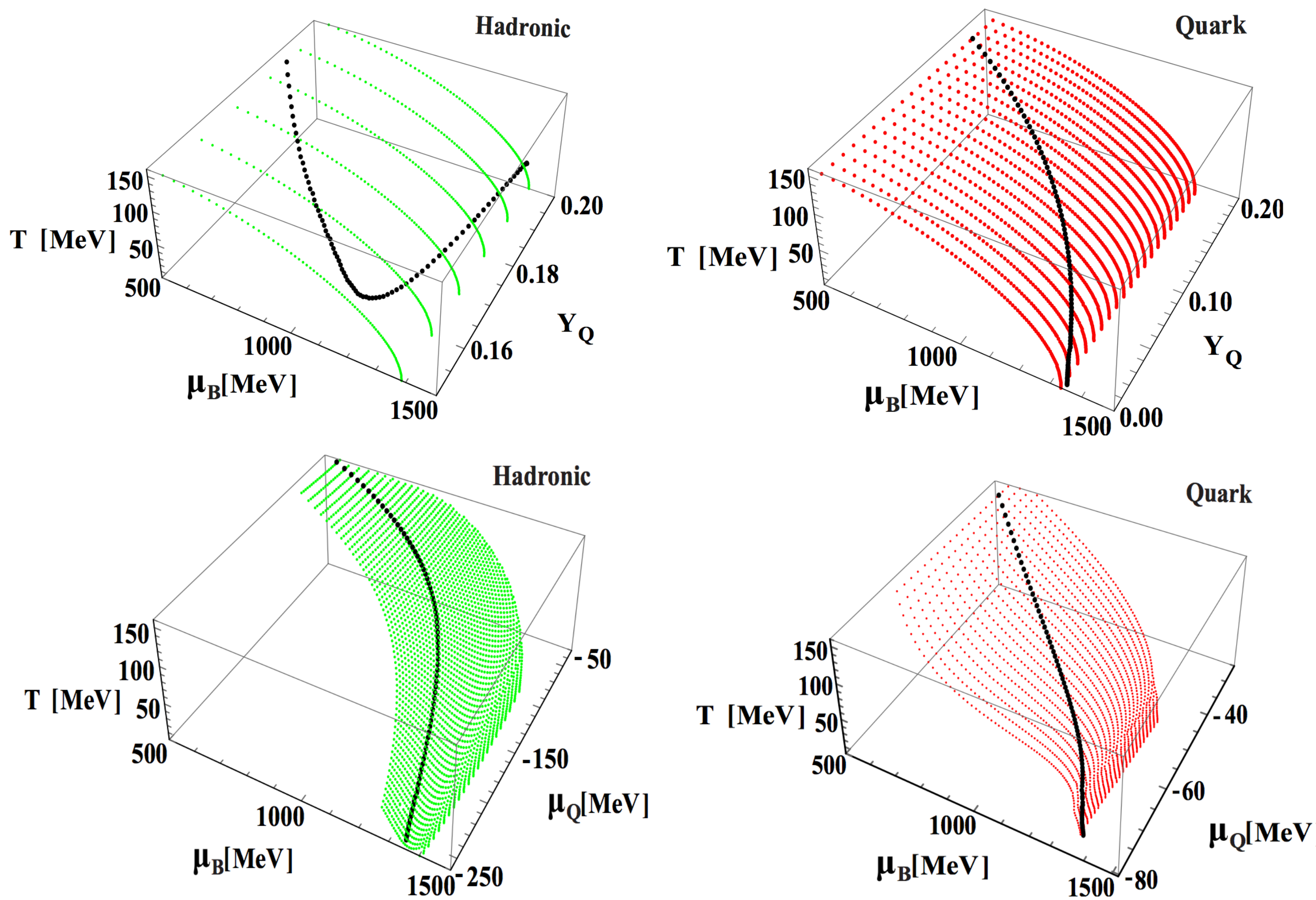


- For finite net strangeness $Y_S \neq 0$, isospin and charge fraction relation is not trivial $Y_I = Y_Q - 0.5 + \frac{1}{2} Y_S$

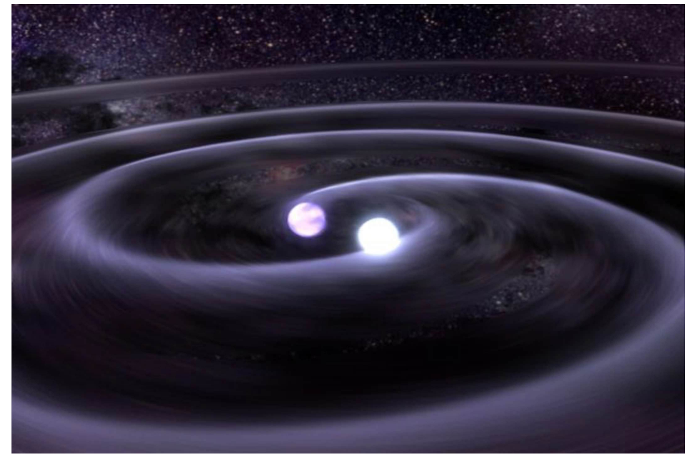


Chemical Equilibrium Lines

- Leptons in chemical eq. with baryons/quarks $\mu_Q = \mu_{e,\mu}$
- Charge neutrality $Y_Q = Y_{lepton}$, finite strangeness $Y_S \neq 0$



Conclusions and Outlook



- Astrophysics provides an ideal testing ground for nuclear physics
- Conditions created in neutron-star mergers are unique (Y_Q, Y_l, Y_S, leptons, S/B…)
- We need to be careful when comparing deconfinement within different scenarios
- Y_Q, Y_l affect significantly the deconfinement to quark matter: μ_B can change by up to 130 MeV and $\mu_{Q,l}$ by up to 330 MeV
- Model dependency is hard to quantify: more realistic models are needed